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Enabling Enhanced Temporal Resolution of Microwave Atmospheric Sounding and Remote Sensing of Clouds and Precipitation: Latest Scientific Results from the Temporal Experiment for Storms and Tropical Systems (TEMPEST) Missions

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The Temporal Experiment for Storms and Tropical Systems – Demonstration (TEMPEST-D) mission demonstrated the first global observations from a multi-frequency microwave radiometer on a CubeSat, operating for nearly three years from 2018 to 2021. This NASA Earth Venture Technology mission exceeded expectations for scientific data quality, instrument calibration, radiometer stability, and mission duration. TEMPEST-D brightness temperatures were validated using scientific and operational microwave sensors, including GPM/GMI and four MHS sensors, operating at similar frequencies to TEMPEST-D channels at 87, 164, 174, 178 and 181 GHz. TEMPEST-D performance was shown to be comparable to or better than much larger operational sensors, in calibration accuracy, precision, stability and instrument noise, during its nearly 3-year mission.

A nearly identical TEMPEST instrument produced by JPL alongside TEMPEST-D for risk reduction was made available to the U.S. Space Force under their mandate to demonstrate low-cost space technologies to improve global weather forecasting. The TEMPEST flight-spare instrument was then integrated with the Compact Ocean Wind Vector Radiometer (COWVR) that had been produced by NASA/JPL for the U.S. Air Force. COWVR and TEMPEST were launched together on December 21, 2021, as part of the Space Test Program – Houston 8 (STP-H8) mission and deployed on the Japanese Experiment Module on the ISS for at least 3 years of operations. COWVR and TEMPEST have performed coordinated, complementary observations of Earth's oceans and atmosphere from the ISS since January 7, 2022. Retrievals of water vapor profiles, clouds, and precipitation from COWVR/TEMPEST-H8 are being performed in collaboration between JPL and Colorado State University.

Atmospheric inversion techniques have been developed to retrieve water vapor altitude profiles, as well as single-layer cloud liquid water and cloud ice water, from TEMPEST brightness temperatures, using ECMWF Reanalysis v5 (ERA5) data as an initial guess. These retrievals are enhanced through the inclusion of geostationary infrared data from GOES-16 ABI channels, increasing the number of levels and reducing the error of water vapor retrieval, particularly in the upper troposphere.

Previous studies have validated the accuracy and precision of TEMPEST-D brightness temperatures using only clear-sky oceanic observations. Recent studies extend the validation of TEMPEST-D and TEMPEST-H8 to include observations over tropical cyclones, hurricanes, and typhoons using GPM-GMI passive microwave brightness temperatures and GPM-DPR active microwave vertical cumulative reflectivity. Such active/passive microwave observations provide the basis for development of surface rain rate estimates and retrieval of the vertical structure of precipitation from combined TEMPEST and DPR observations.

The accuracy, precision, and long-term stability of TEMPEST-D microwave radiometer operation on a 6U CubeSat throughout the three-year mission demonstrated the potential for enhancement of temporal resolution of atmospheric sounding, clouds and precipitation observations from low-Earth orbit using constellations of small satellites. To this end, the TEMPEST-H8 mission and NASA EVM-3 INCUS mission are enabled in large part by the success of TEMPEST-D, along with that of JPL's RainCube, the first weather radar on a CubeSat.